# Novel Silicon Stripixel Detectors on High Resistivity p-type Magnetic Czochralski Silicon Wafers for Super LHC.


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## I. INTRODUCTION

Recently, a novel detector structure based on interleaved pixel electrodes arranged in a projective x-y readout has been developed at BNL [1-2]. With this novel detector structure, named as "stripixel", a 2d-position sensitive detector can be made with single-sided process using double-metal technology. Two prototypes of stripixel detectors had been fabricated at BNL for the PHENIX Upgrade at RHIC [3-5]. Laser, electron source and beam tests on these prototype detectors have shown 2d-position sensitivity with resolutions of 25 μm in both x and u directions (both are 80 μm in pitch, and a stereo angle of 4.6°) [4].

For applications in SLHC, where the luminosity will be increased by a factor of 10, the stripixel detector may be a good candidate in the inter-medium strip detector region. Since in this region in the SLHC, the detector strip length may be limited to a few cm's in length due to occupancy requirements. This is a excellent fit for the stripixel detectors since short strip length will compensate the increase in strip capacitance due to the interleaving scheme in stripixel structure [2]. The simplicities in stripixel processing and geometry can result in significant cost reductions in material, processing, assembly and readout scheme. Another key issue for the SLHC with increased luminosity is the radiation hardness of the detectors. The highest charged particle fluence in the inter-medium region for strip detectors is about $2.0\times10^{15}$ $n_{eq}$ (1 MeV neutron equivalent)/$cm^2$. One of the main research approaches to improve Si sensor radiation hardness is to oxygenate Si by introducing oxygen into Si during the detector processing [6-10]. With its natural high oxygen concentration (over $10^{18}$ /$cm^3$), high resistivity ($\gtrsim$ 1 kΩ·cm) Magnetic Czochralski (MCZ) Si detectors are a candidate for more improved radiation hardness [11-12]. In this work, a new detector system using the novel stripixel structure with p-type MCZ Si substrate ($n^+/p/p^+$) is proposed for the US ATLAS Upgrade for SLHC. With p-type substrate, the single-sided process advantage in stripixel processing is preserved as compared to n on n ($n^+/n/p^+$) detectors. In addition, electrons will be collected with fast rate, no space charge sign inversion will take place at any radiation level, and detectors can work in partial depletion mode after extremely high fluence radiation.

Detector design, detector chip and bonding layout, as well as simulations in detector processing and electric properties before and after irradiation will be given.

## II. DETECTOR DESIGN AND LAYOUT

As shown in Fig. 1, the basic stripixel concept is to divide an ordinary pixel into two parts: the x (or u)-pixel and y-pixel and read x and y pixels by x and y strips in a projective way. In order to ensure a signal in both x and y pixel when a particle passes through the detector, the two parts within a pixel should be interleaved in such a way that the maximum distance between them any where should be smaller than the full width at half maximum (FWHM) of the diffusion cloud during the drifting of the induced charge [2]. For the single cell design for US ATLAS Upgrade, the pixel pitches are 620 μm in x and 50 μm in y. The y-strip pitch and u-strip pitch are both 50 μm. The stereo angle between u and y strips is 4.6°.

The line widths for both x and y-pixels are 5 μm, with a gap of 3.33 μm between them. The maximum distance between x and y pixels is thus 8.33 μm, less than FWHM = 9 μm for the diffusion cloud [2]. The detector is to be made on p-type MCZ Si with resistivity of about 3 kΩ-cm.

Fig. 2 shows the schematics of detector processing and processing parameters. A uniform field (or spray) $p^+$ implant will be made on the front side to provide channel separation between the $n^+$ pixels to be implanted later. With this field implant, only five mask steps are needed for the detector processing of this new detector system.

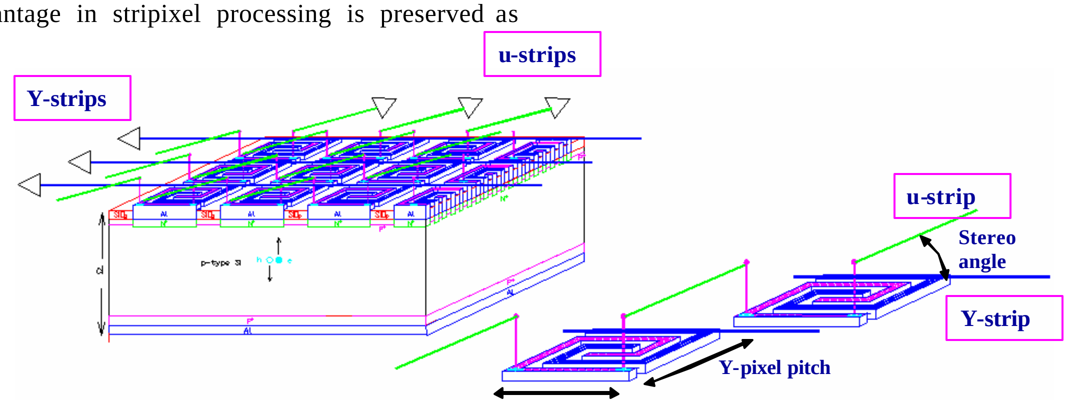


Fig. 1 Schematics of the proposed stripixel Si detector system for US ATLAS Upgrade


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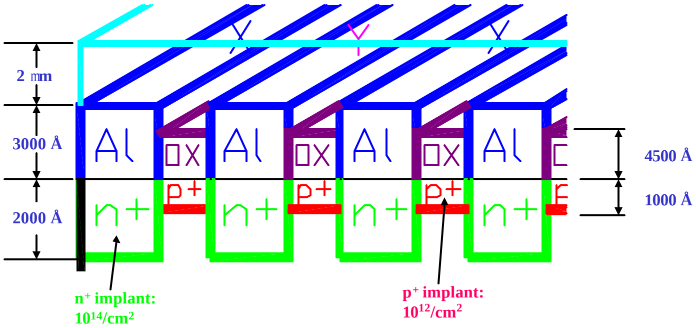


Fig. 2 Schematics and parameters for the processing for the proposed stripixel Si detector system for US ATLAS Upgrade

Shown in Fig. 3 is the left half of a detector chip with chip size of 2.56 cm $\times$ 6.0 cm. The right half of the chip is a mirror image of the left along the mirror line indicated in the figure. Although the strips in the left half and those in the right half are separated, there is no guard ring between them; therefore there is no dead space. The strip length in either half is 3 cm, with 512 X (u) strips and 512 Y strips in each half. Both X and Y strips are read out from the side using the same double metal process technology already presented in the stripixel processing (no 3$^{rd}$ metal needed). The readout lines are grouped in 128 strip bunches, with 48 $\mu$m bonding pitch with stacked bonding pads of 80 $\mu$m$\times$ 300 $\mu$m in size.

## III. DETECTOR SIMULATION

Simulations before irradiation and after irradiation by charged particles up to $1.0\times10^{16}$ $n_{eq}/cm^2$ have been performed on novel stripixel Si detectors made on p-type high resistivity MCZ wafers. The introduction rate of radiation-induced negative space charges is obtained from ref. [12]. Fig. 4 shows the detector electrical properties after being irradiated charged particles to $2.0\times10^{15}$ $n_{eq}/cm^2$, the highest fluence for the strip detectors in the inter-medium region in SLHC. It is clear that, even after such high fluence of irradiation by charged particles, the detector can still be fully depleted at a modest bias voltage of 400 volts. Further simulations have shown that, for higher fluences than $2.0\times10^{15}$ $n_{eq}/cm^2$, the detector may be depleted at higher bias voltages (<1000 volts). However, micro breakdown along the surface may occur before such biases are reached. In this case, the detector can be operated at partial depletion mode with lower biases (400 volts<V<1000 volts) keeping a significant fraction of the volume sensitive. However, at fluences close to $1.0\times10^{16}$ $n_{eq}/cm^2$, the trapping effect will dominate; and this is the limiting factor for detector charge collection efficiency (CCE), and other approaches may be needed in addition to the approach proposed here.

## IV. REFERENCES


[1] Z. Li, BNL Internal Report, BNL #67527, June 10, 2000

[2] Z. Li, “Novel Silicon Stripixel Detector: Concept, Simulation, Design, and fabrication”, BNL 71393-2003JA, Nucl. Instr. & Meth. A 518, Vol. 3, (2004) pp738-753.

[3] Z. Li et al., “Novel Silicon Stripixel Detector for PHENIX Upgrade”, presented on 9th Pisa Meeting on Advance Detectors, May 25-31, 2003, La Biodola, Isola d’Elba, Italy, Nucl. Instr. & Meth. A 518 (2004) 300-304.

[4]. J. Tojo et al., “Development of a Novel Silicon Stripixel Detector for RHIC-PHENIX Detector Upgrade”, presented on IEEE Nucl. Sci. Symp., October 19-25, 2003, Portland, Oregon, to be published in IEEE Trans. Nucl. Sci.

[5]Z. Li et al., “Development of 2nd prototype of Novel Silicon Stripixel Detector for PHENIX Upgrade”, presented on 10th Vienna Conference on instrumentation, Feb. 16-21, 2004, Vienna, Austria, accepted by Nucl. Instr. & Meth. A.

[6] Z. Li, H. W. Kraner, E. Verbitskaya, V. Eremin, A. Ivanov, M. Rattaggi, P. G. Rancoita, F. A. Rubinelli, S. J. Fonash, C. Dale, and P. Marshall, “Investigation of the Oxygen-Vacancy (A-Center) Defect Complex Profile in Neutron Irradiated High Resistivity Silicon Junction Particle Detectors”, IEEE Trans. Nucl. Sci., Vol. 39, No. 6, (1992) pp 1730-1738.

[7] A. Ruzin and CERN Rd48 Collaboration, “Recent results from the RD-48 (ROSE) Collaboration” Nucl. Instr. & Meth. A447, (2000) pp116-125

[8] RD48 Status Report, CERN/LHCC 2000-009, December 1999.

[9] G. Lindstroem, and CERN RD48 Collaboration, “Radiation hard silicon detectors––developments by the RD48 (ROSE) collaboration”, Nucl. Instrum. & Meth. A466, (2001) pp308-326.

[10] G. Lindström, “Radiation Damage in Siliocon Detectors”, Nucl. Instrum. & Meth. A512 (2003) pp30-43.

[11] J. Härkönen, E. Tuominen, E. Tuovinen, P. Heikkilä, V. Ovchinnikov, M. Yli-Koski, L. Palmu, S. Kallijärvi, H. Nikkilä, T.O. Niinikoski, V. Eremin, E. Verbitskaya and O. Anttila, “Processing microstrip detectors on Czochralski grown high resistivity silicon”, ”, Nucl. Instr. & Meth., A 514 (2003) 173-179.

[12] Z. Li et al, “Radiation Hardness of High Resistivity Magnetic Czochralski Silicon Detectors after Gamma, Neutron and Proton Radiations”, accepted by IEEE Trans. Nucl. Sci. (in press).


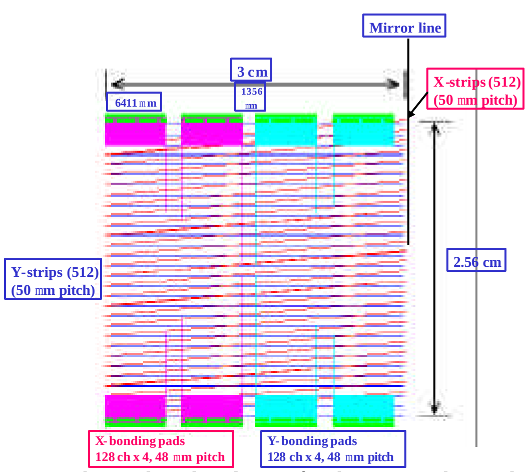


Fig. 3 Detector chip and readout layout for the proposed stripixel Si detector system for US ATLAS Upgrade

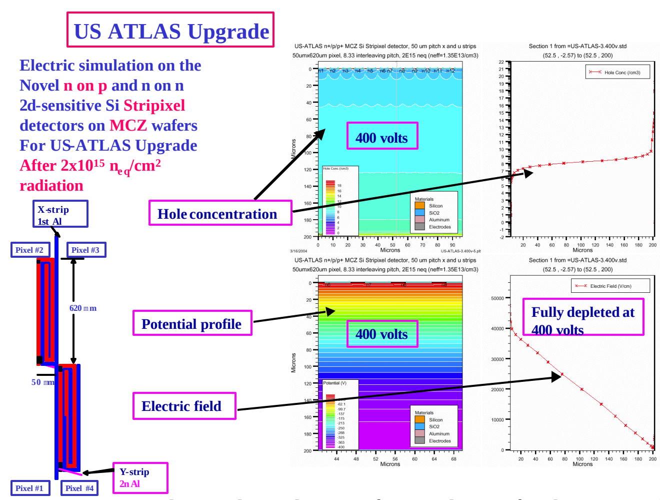


Fig. 4 Detector electrical simulations after irradiation for the proposed stripixel Si detector system for US ATLAS Upgrade